3.0 Soil Reinforcement

3.1 Slopes

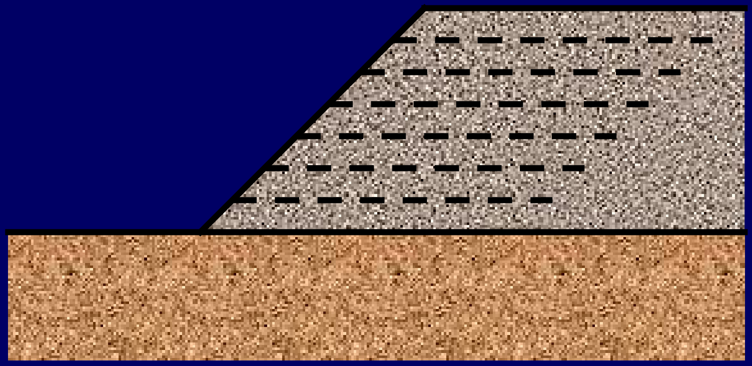
3.2 Embankments

3.3 Walls

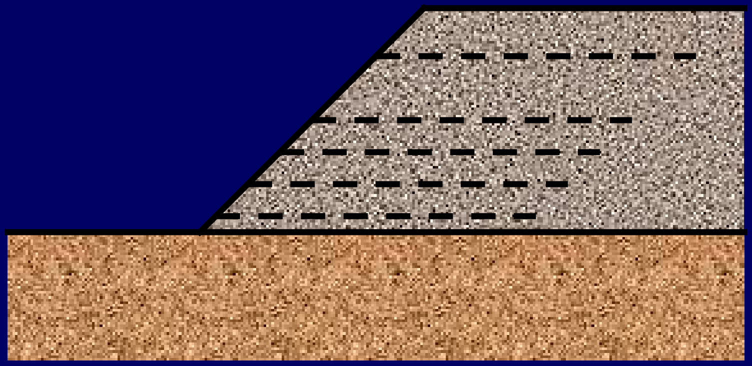
3.1 Soil Reinforcement for Slopes

- most natural slopes become unstable after about 2(H)-to-1(V) (26.5°)
- use GT or GG reinforcement to increase either the slope angle or height
- essentially no limit, except for erosion
- various placement patterns are possible

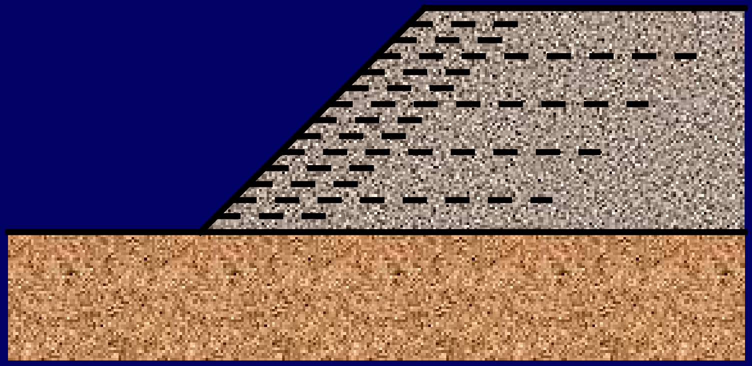
Placement patterns for reinforcement



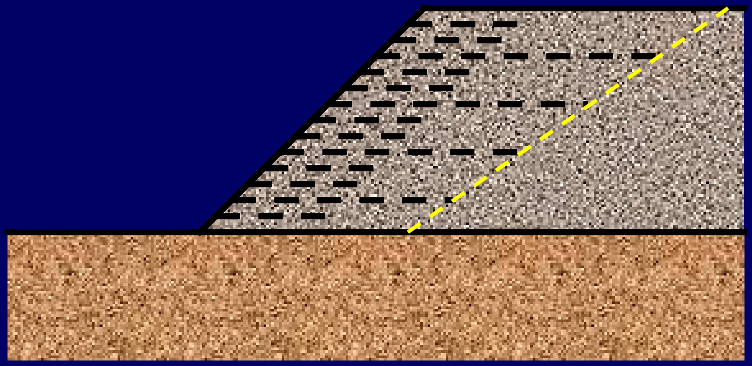
(a) Even spaced-even length



(b) Uneven spaced-even length



(c) Even spaced-even length with short facing layers



(d) Even spaced-uneven length with short facing layers

Slope Reinforcement Design Concepts

- modification of circular arc method

$$FS = \frac{M_R + \sum_{i=1}^{m} T_i y_i}{M_D}$$

where

M_R = moments resisting failure due to soil strength,

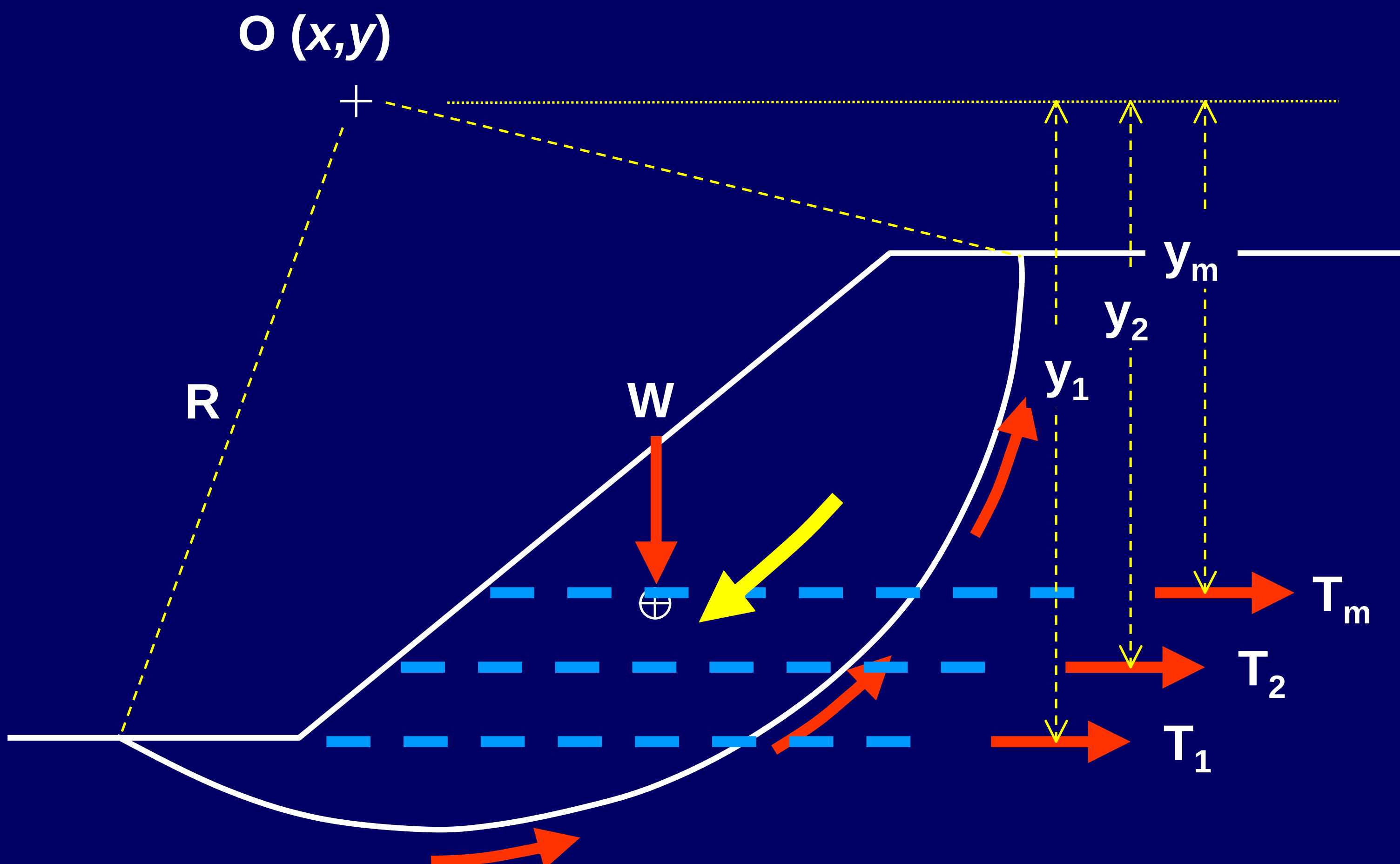
M_D = moments driving, or causing, failure due to gravity, seepage, seismic, dead, and live loads,

T_i = allowable reinforcement strength which provides a force resisting failure [$=T_{ult}(1/\Pi RF)$]

y_i = appropriate moment arm(s), and

m = number of individual reinforcement layers

Circular Arc Slope Stability Analysis



Slope Reinforcement Design Concepts *(cont'd)*

- **GT or GG strength must be allowable, i.e., reduction factors must be included**
- **some questions remain over moment arm (vertical distance is more conservative than the radius)**
- **layer interaction is not considered**
- **soil/GS strain compatibility must be considered**
- **use circular arc or 2-part wedge**

Example using circular arc method:

For a failed soil slope of known centroid and radius resulting in a resisting moment of 2010 kN/m and a driving moment of 2570 kN/m, determine

(a) the FS without reinforcement,

(b) the number of layers of a candidate GG with an ultimate strength of 78.7 kN/m and Π(RF) of 11.8. The average centroid of the reinforcement is 14.3 m and the factor of safety is required to be 1.4. (Values are from Calif. DOT case history).

Solution: (a) FS for the nonreinforced case

$$FS = \frac{M_R}{M_D}$$

$$= \frac{2010}{2570}$$

$$= 0.78\text{ , i.e. NG}$$

(b) The GG-reinforced case is

$$T_{allow} = T_{ult} / \Pi RF = 78.7 / 11.8$$

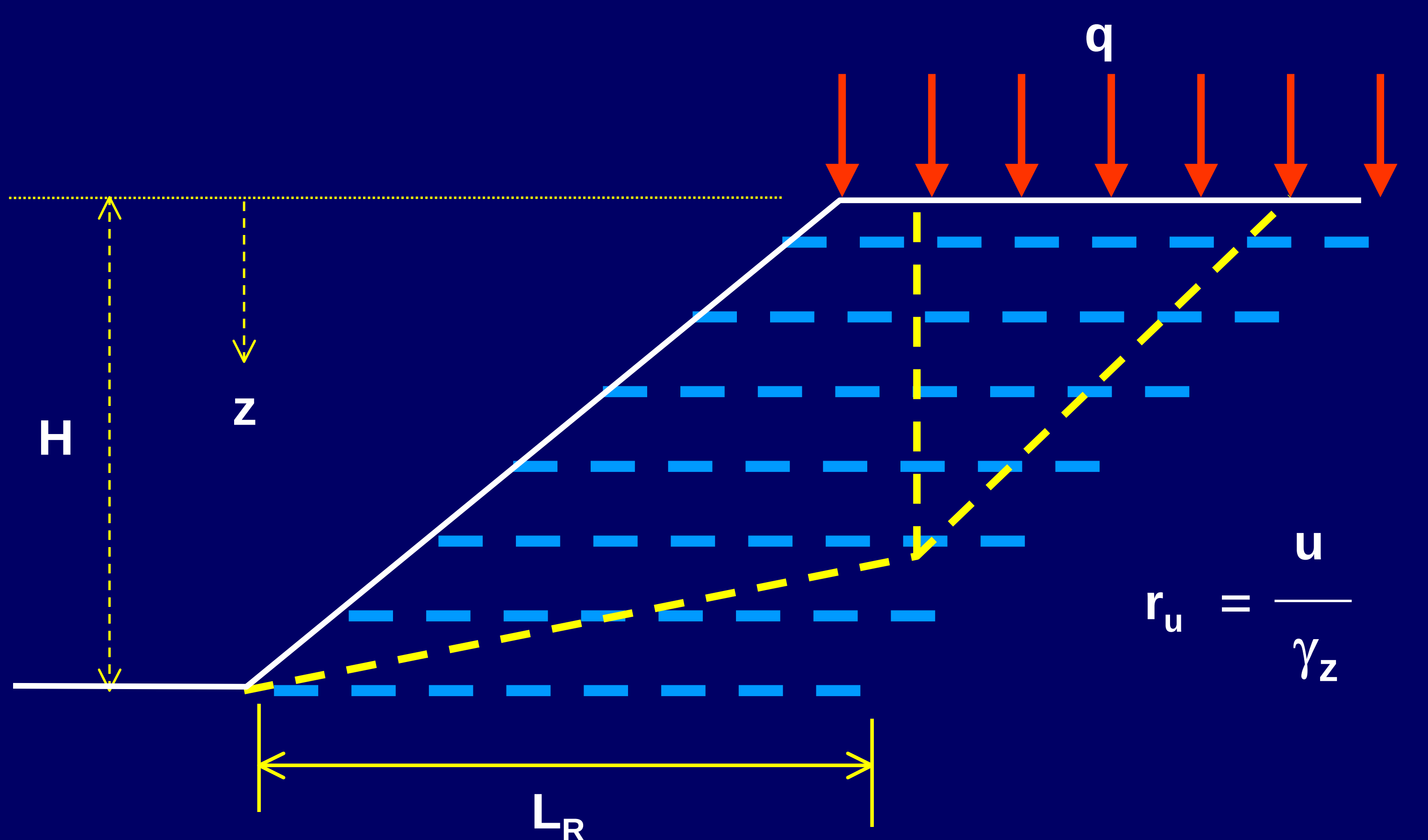
$$= 6.67\text{ kN / m}$$

$$FS = \frac{M_R + (n)(T_{allow})(Y_{ave})}{M_D}$$

$$1.4 = \frac{2010 + (n)(6.67)(14.3)}{2570}$$

$$n = 16.6\text{, use 17 layers}$$

Slope Stability Analysis by Wedge method



Example using wedge method:

Construct a 70° slope to 10 m height. Reinforce with GG with T_{ult} = 180 kN/m and ΠRF = 4.12. Use FS = 1.4. The soil is granular with γ = 18 kN/m^3, ϕ = 30°, c = 0, r_u = 0. Determine the number of layers, spacing and length.

Solution: **A number of researchers have developed design guides; Ingold, Murray, Jewell (which follows), Leshchinsky, Schneider, Holtz, Ruegger and Schmertmann. By observation, the slope at 70° to the vertical without reinforcement is in a failure state (i.e., FS << 1.0) and is in need of reinforcement. The design procedure is given in steps.**

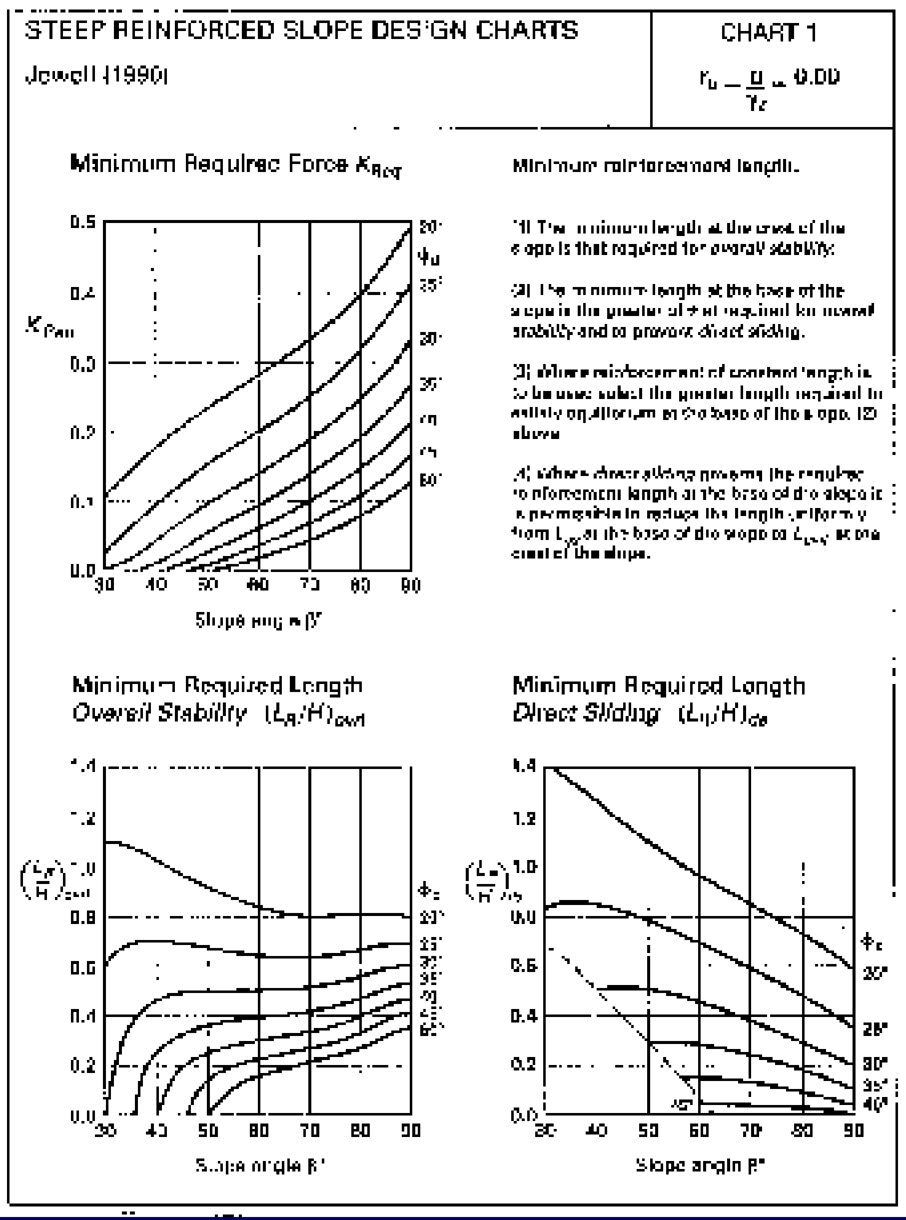
(a) Calculate the allowable strength on the basis of reduction factors and then determine the design strength which includes the factor of safety

$$T_{ult} = 180\,\mathrm{kN/m}$$

$$T_{allow} = \frac{180}{4.12} = 43.7\,\mathrm{kN/m}$$

$$T_{des} = \frac{43.7}{1.4} = 31.2\,\mathrm{kN/m}$$

Steep Reinforced Slope Design Chart (r_u = 0.0)



After R.A. Jewell, Jour. G & G, Vol. 10, No3, 1991, pp. 203-233

Example using wedge method *(cont'd)*

(b) Determine the necessary values from Jewell's chart for $r_u = 0.0$, $\beta = 70°$ and $\phi = 30°$. This results in the following:

$$K_{req} = 0.19$$

$$(L / H)_{ovrl} = 0.51$$

$$(L_R / H)_{ds} = 0.38$$

(c) Calculate the spacing S_v, at the base of the slope where the stresses are the greatest

$$S_v = \frac{T_{design}}{K_{reqd}\gamma z_{max}} = \frac{31.2}{(0.19)(18)(10)} = 0.91 \text{ m}$$

$$n = \frac{H}{S_v} = \frac{10}{0.91}$$

= 11 layers (evenly spaced)

Example using wedge method *(cont'd)*

(d) Select the reinforcement length

- if $(L_R/H)_{ovrl}$ > $(L_R/H)_{ds}$, use constant length = $(L_R/H)_{ovrl}$
- if not, use constant length = $(L_R/H)_{ds}$ or taper the lengths from $(L_R/H)_{ds}$ at the base to $(L_R/H)_{ovrl}$ at the crest

Since 0.51 > 0.38, use $L_R/H = 0.51$

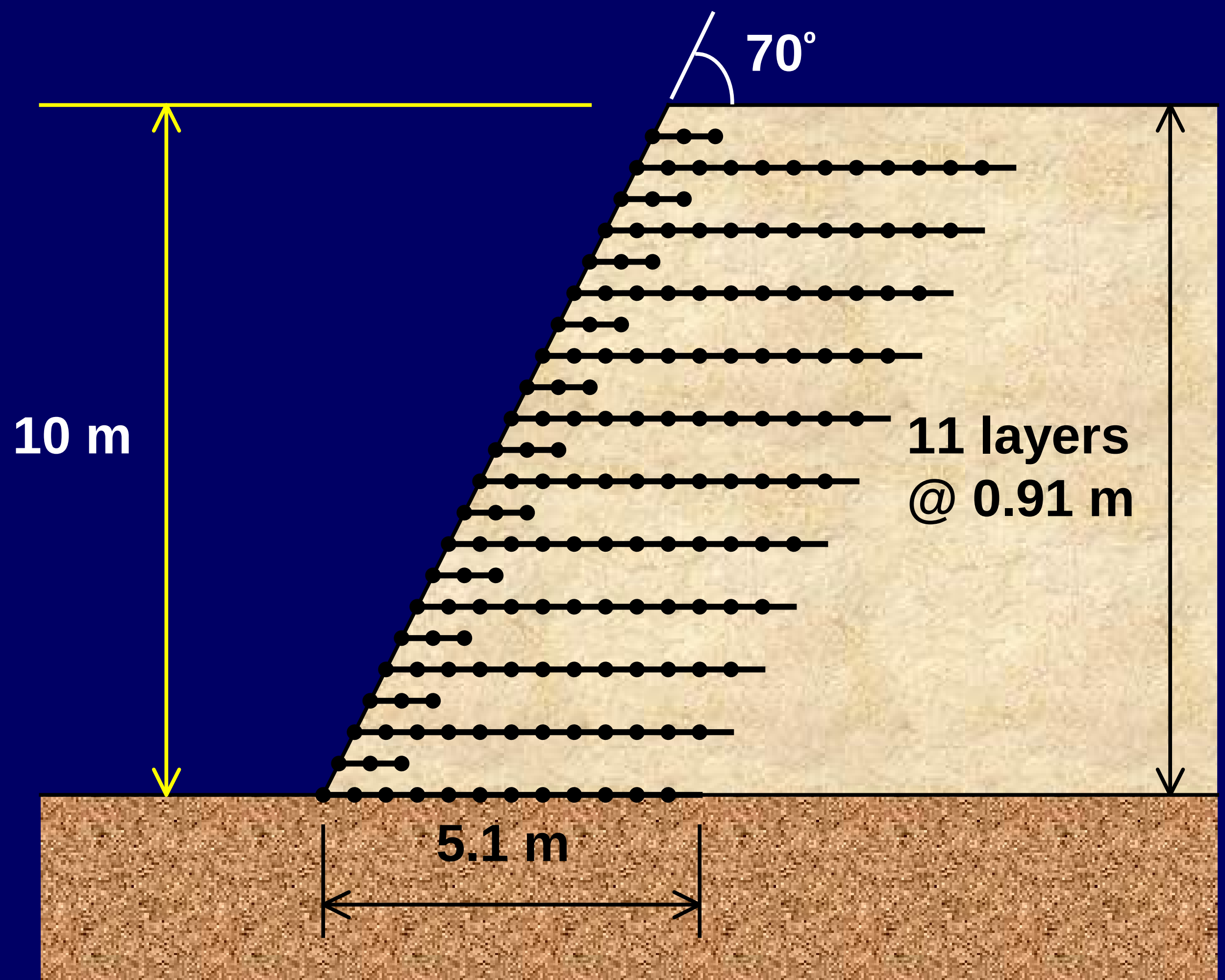
$\therefore$ L_R = 5.1 m throughout

(e) The overturning, sliding and bearing capability must be checked by conventional methods using the entire reinforced mass.

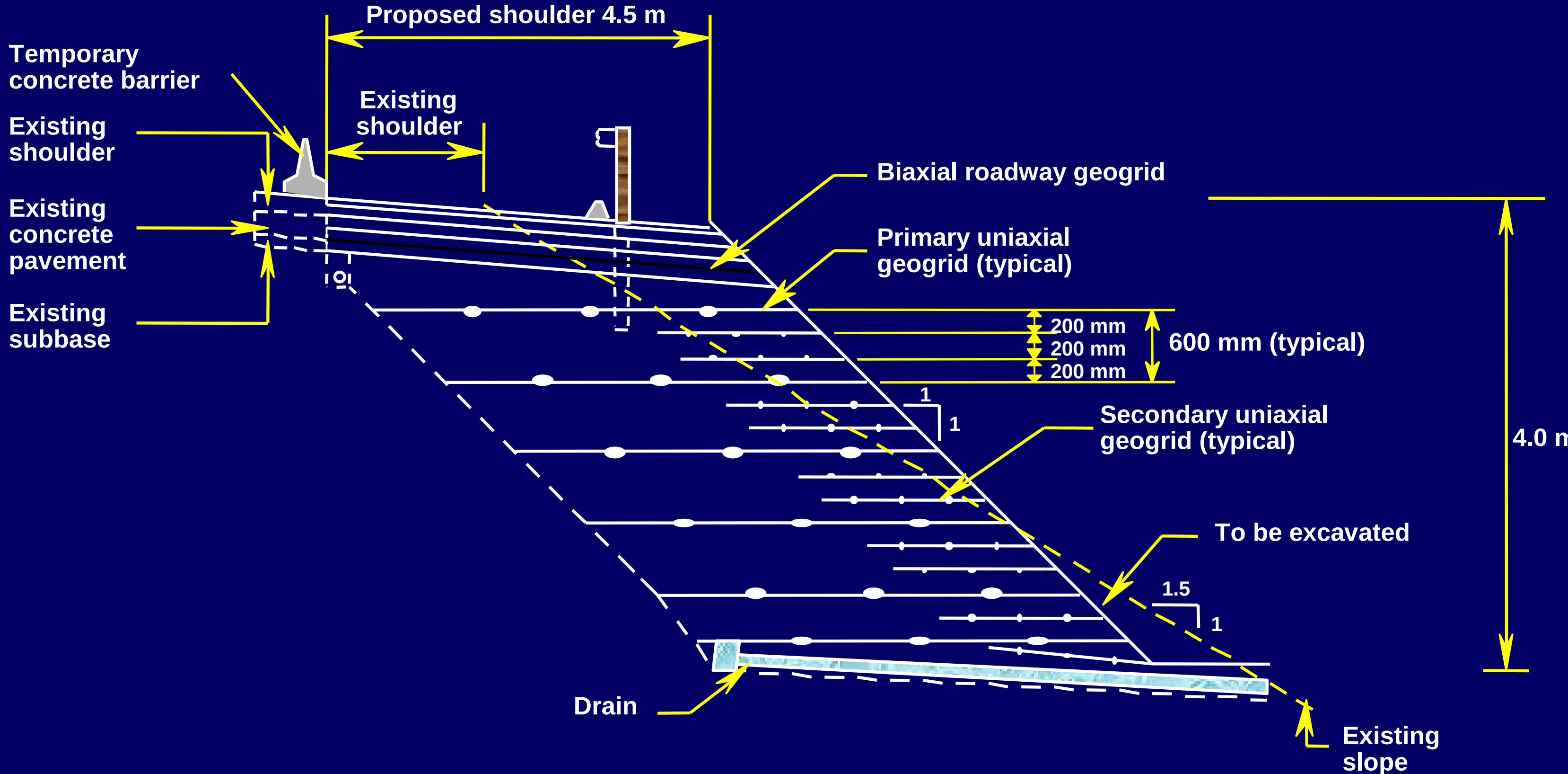
(f) Check between different geogrid behavior in the anchorage zone behind the hypothetical shear plane. Such differences must be considered from experimental results. If concern is felt in this regard for one geogrid product versus another, the designer always has the option of lengthening the geogrids over that recommended by the design charts.

(g) Sketch the final reinforced slope and provide for miscellaneous details as shown below, e.g., use short (secondary) geogrids between the primary reinforcement and adjacent to the slope for compaction and against surface erosion.

Result of previous design example



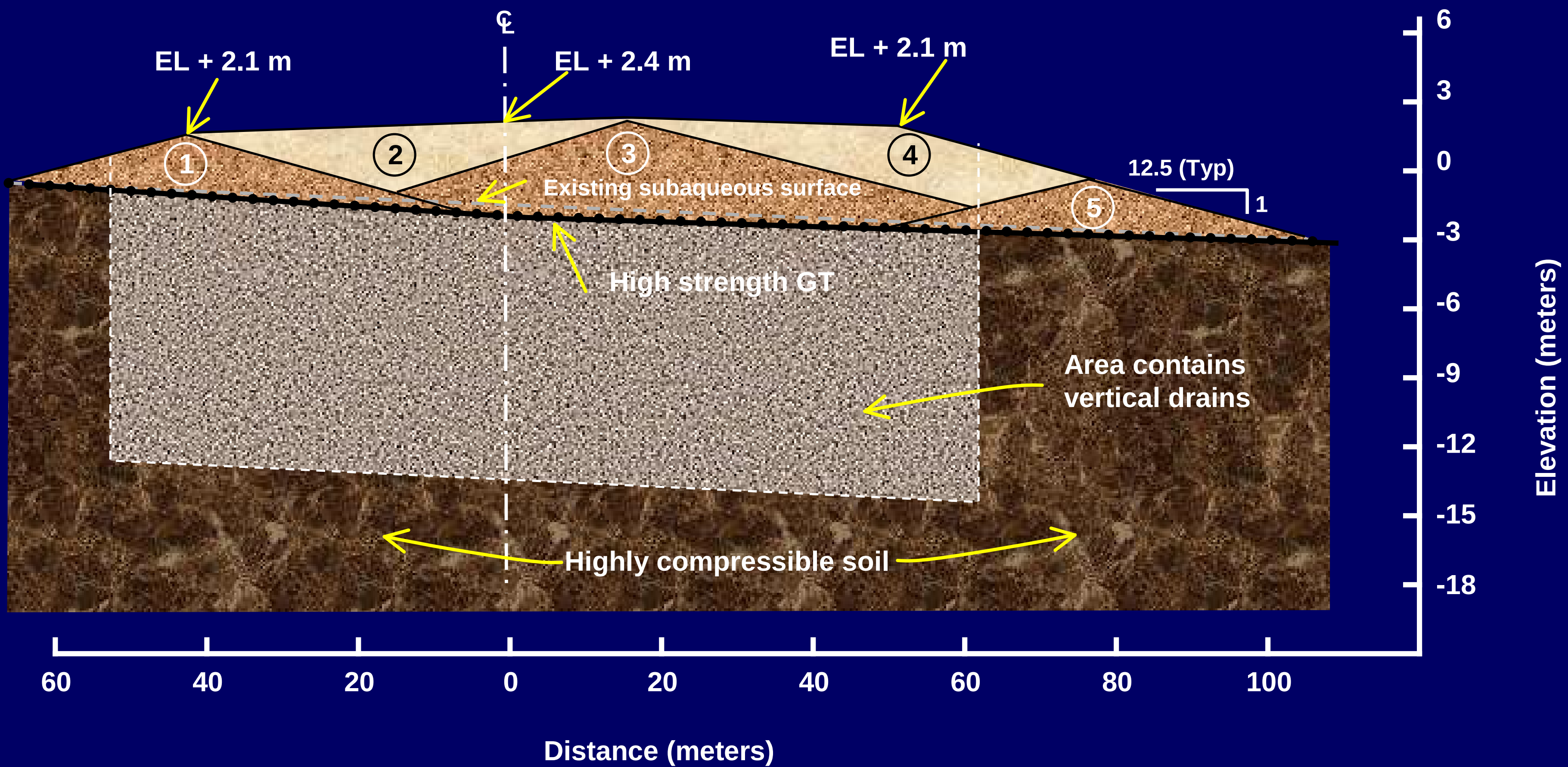
Pennsylvania Turnpike shoulder widening project



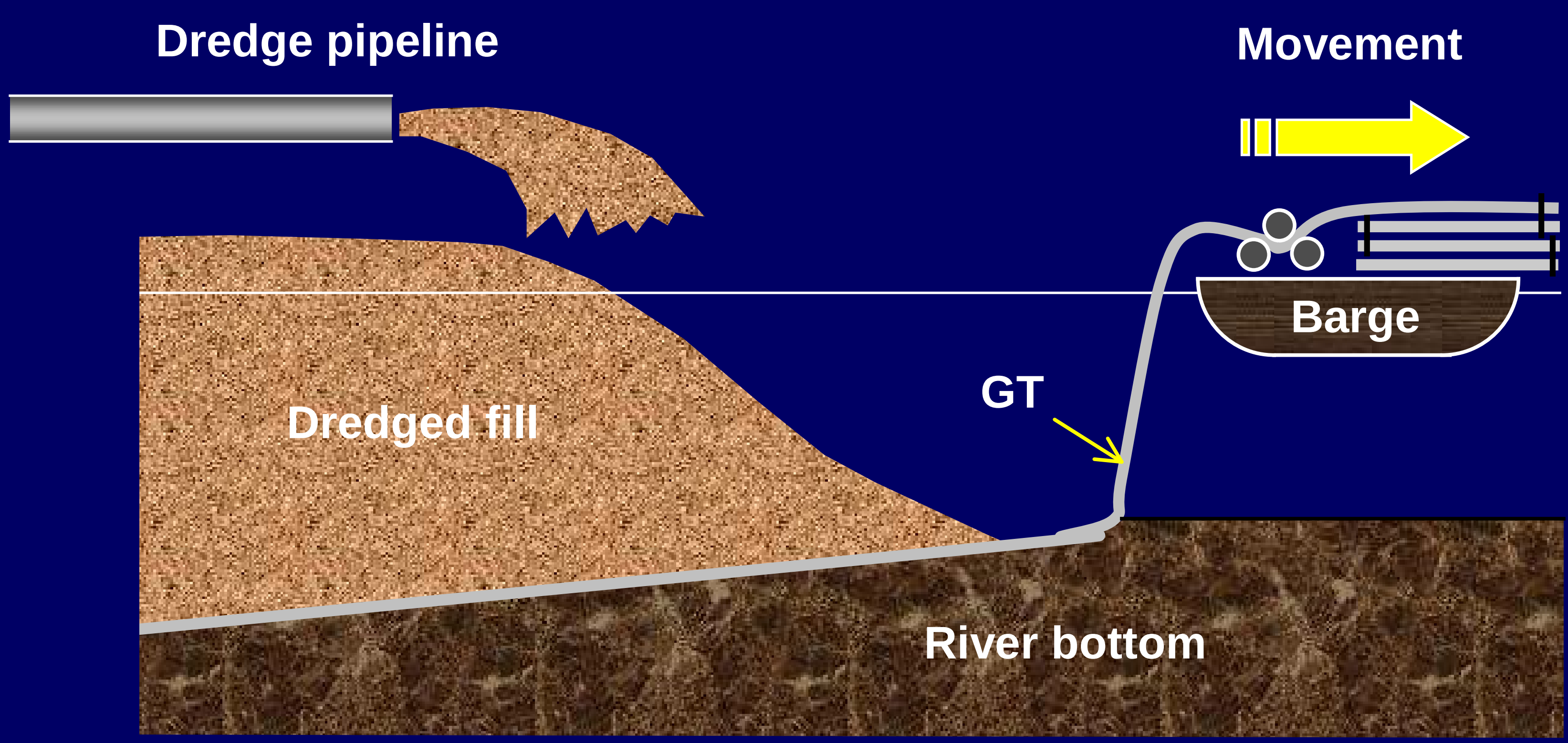
3.2 Foundation Reinforcement for Embankments

- **Technique pioneered by Corps of Engineers (WES and various Districts)**
- **Need is to construct dikes (embankments) for containment of river dredging material**
- **River bottom foundation soils have extremely low strength**
- **See Sprague, C. J. and Koutsourais, M., ASCE Geotech. Spec. Publ. #30, 1992, pp. 1129-1141 for review of sites**
- **First example is COE Wilmington Harbor South Disposal Area; which is a linear fill**
- **Second example is Seagirt, MD Port Development projects; which is a areal fill**

Embankment (Linear Fill) of Wilmington Harbor South Disposal Area



Geotextile and dredged fill placement at Wilmington Harbor

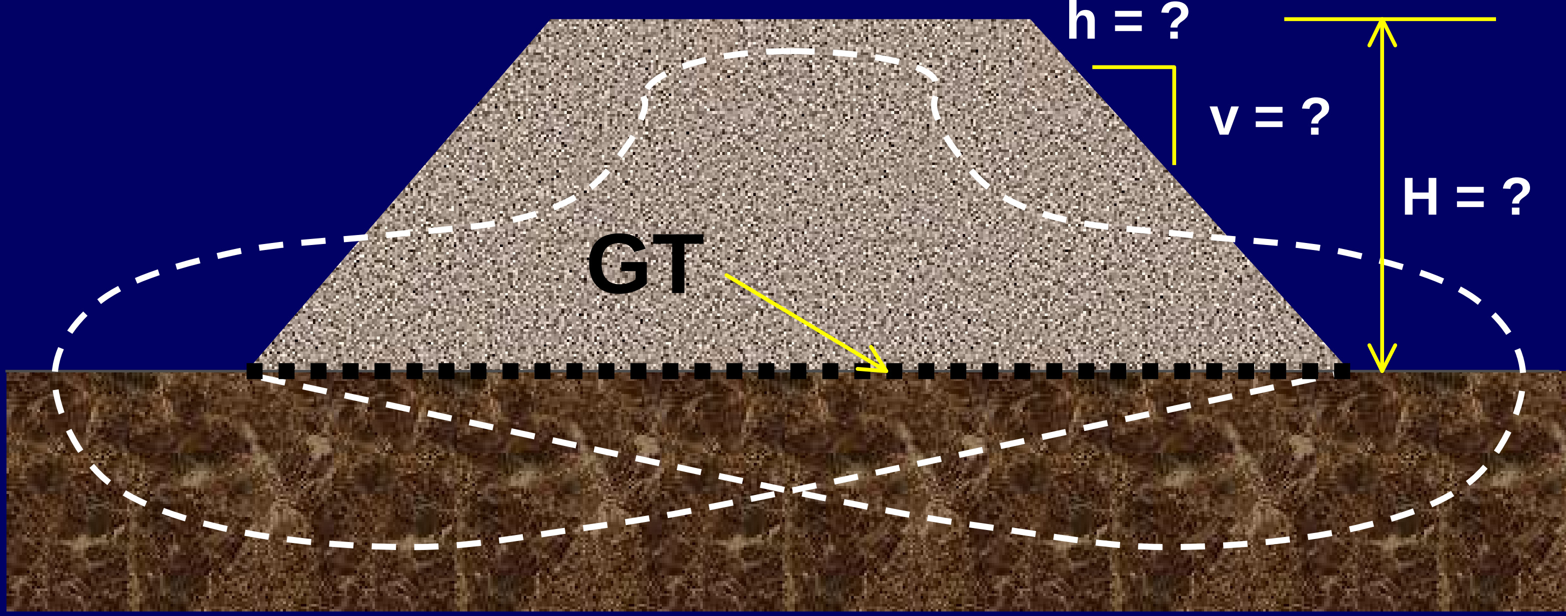


Example of Areal Fill on Soft Foundation
Seagirt Maryland Port Development

- recent hydraulically placed very soft foundation soil
- 50 ha of high strength GT placed directly on soft foundation soil
- 1-m drainage sand followed by wick drains
- 3-m soil surcharge placed on drainage sand
- rapid consolidation and then removal of portion of surcharge, followed by final paving

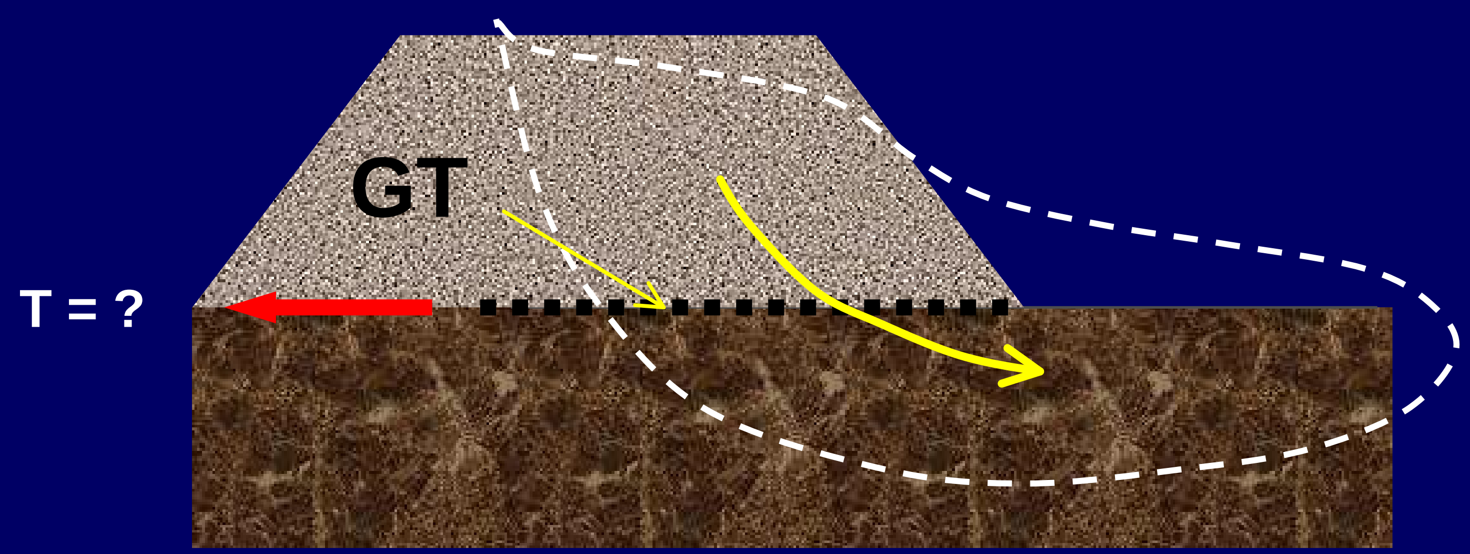
Foundation Reinforcement Design Concepts

(a) bearing capacity → overall embankment geometry



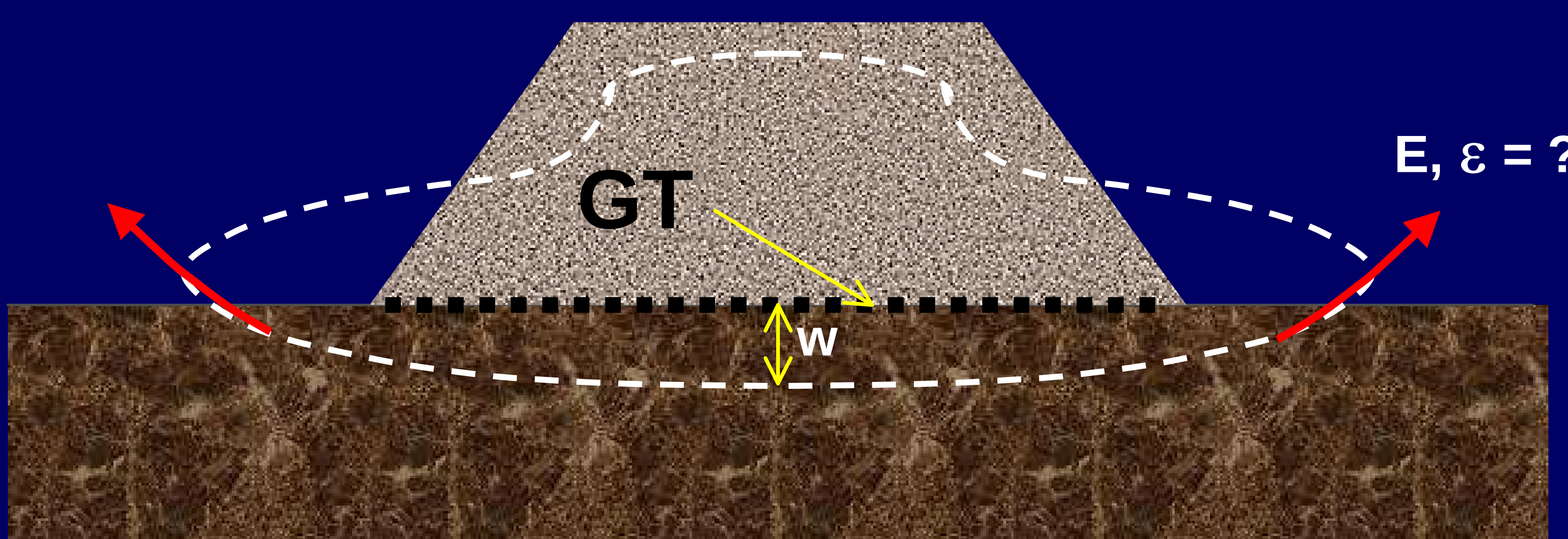
Foundation Reinforcement Design Concepts

(b) global stability → **strength design in major principal stress direction**



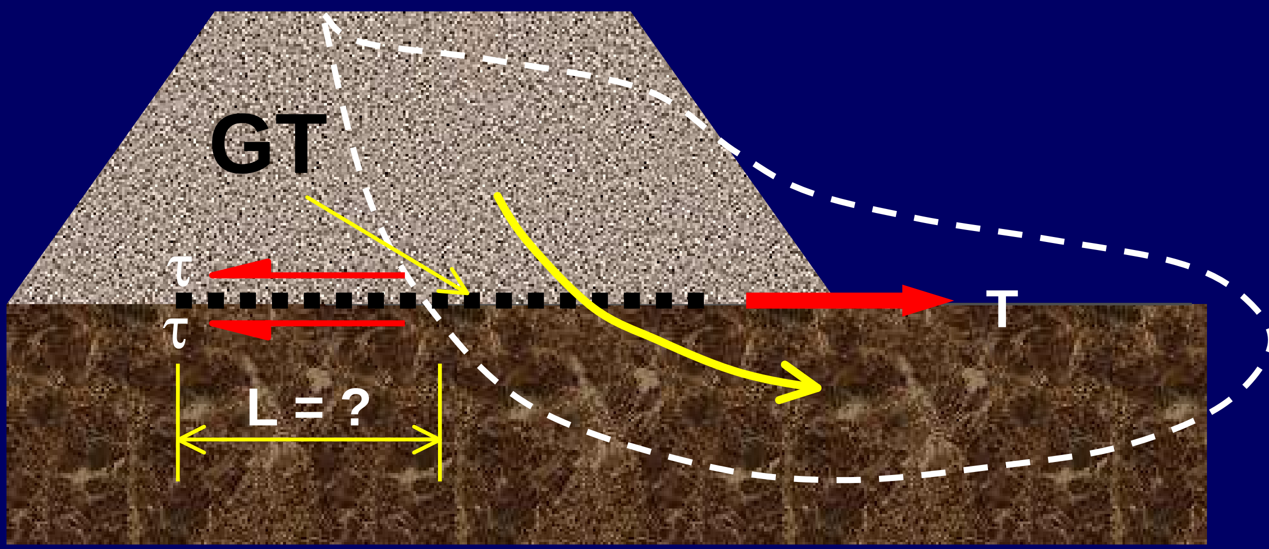
Foundation Reinforcement Design Concepts

(c) elastic deformation $\rightarrow$ modulus and maximum strain in major principal stress direction



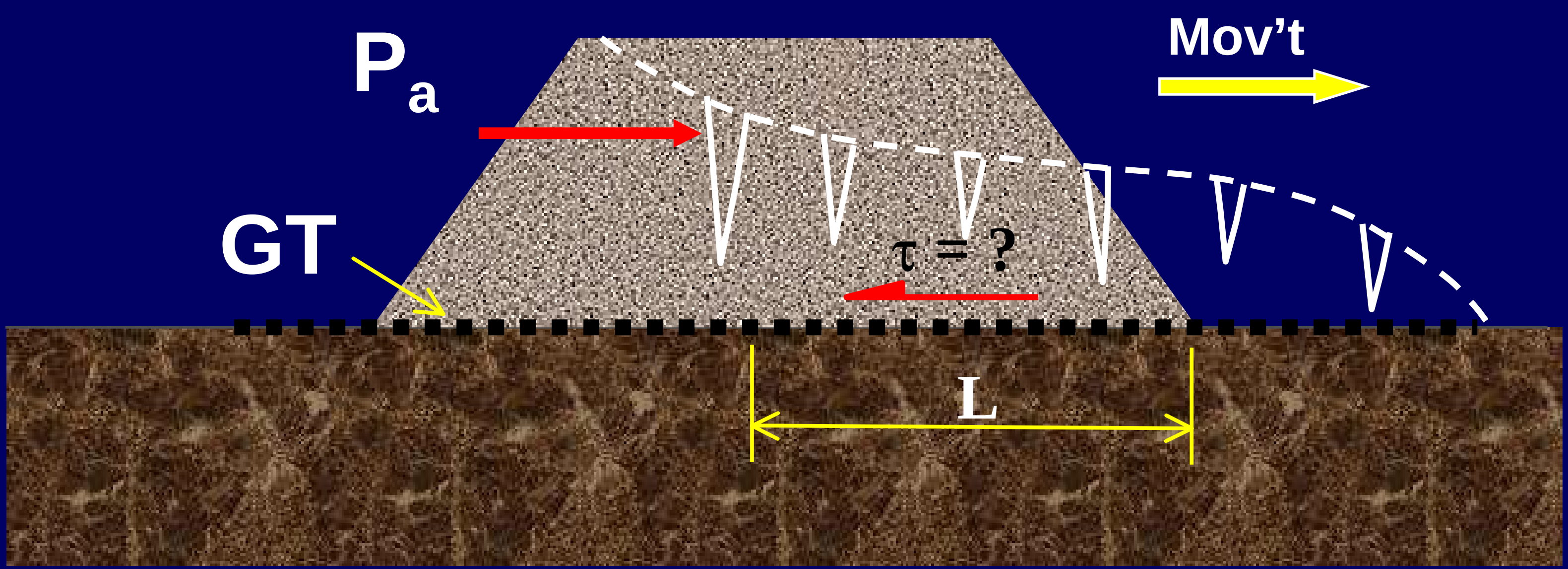
Foundation Reinforcement Design Concepts

(d) pullout or anchorage → anchorage length behind slip plane



Foundation Reinforcement Design Concepts

(e) lateral spreading $\rightarrow$ frictional properties of backfill soil to geotextile



Comparison of Geotextile Specifications for Two High Strength Stabilization Projects

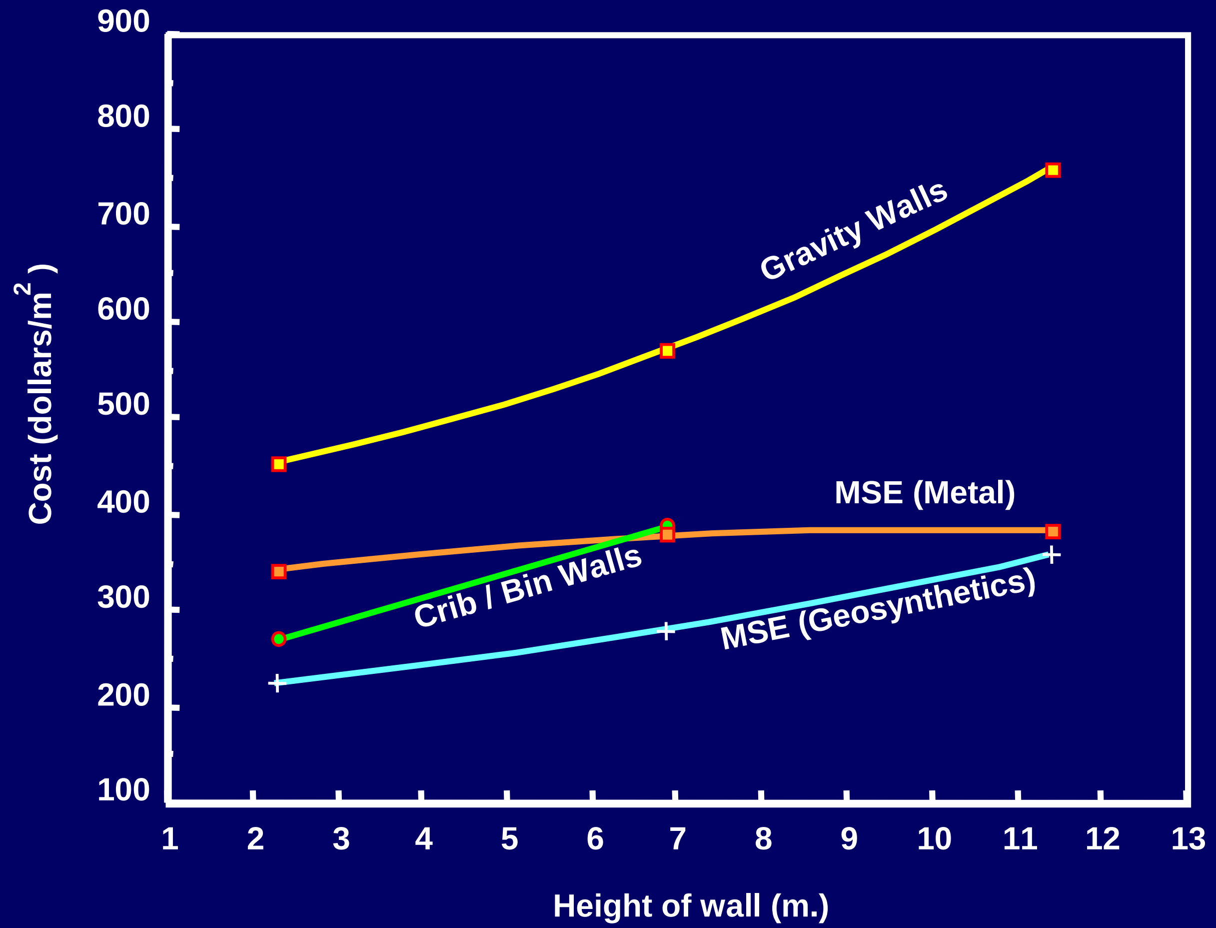
Geotextile Specification Values	Linear Fill (Containment Dike; Wilmington Harbor; Corps of Engineers)	Areal Fill (Industrial Development; Seagirt, Maryland; Maryland Port Admin.)
Polymer Type	PET	PP & PET
Tensile Strength (kN/m)	260	180
Modulus (kN/m)	3300	500
Elongation (%)	10-35	15-35
Stiffness (mg-cm)	-	30,000
Friction Angle (deg.)	30	30
Seam Strength warp (lb./in.) weft (lb./in.)	 none 140	 105 105
Seam Type	J	J
Seam Thread Type	PET	PA; PET

3.3 Soil Reinforcement for Walls

- Reinforced Earth® by Vidal in 1950s
- replaced concept of rigid concrete walls (gravity and cantilever) with flexible walls
- progression of type of reinforcement material
  - smooth steel straps
  - nubbed steel straps
  - welded steel wire mesh
  - geotextiles
  - geogrids
- properly called mechanically stabilized earth (MSE) walls
- low cost of GS reinforced walls are very impressive

Mean value of retaining wall costs compared to one another by wall type

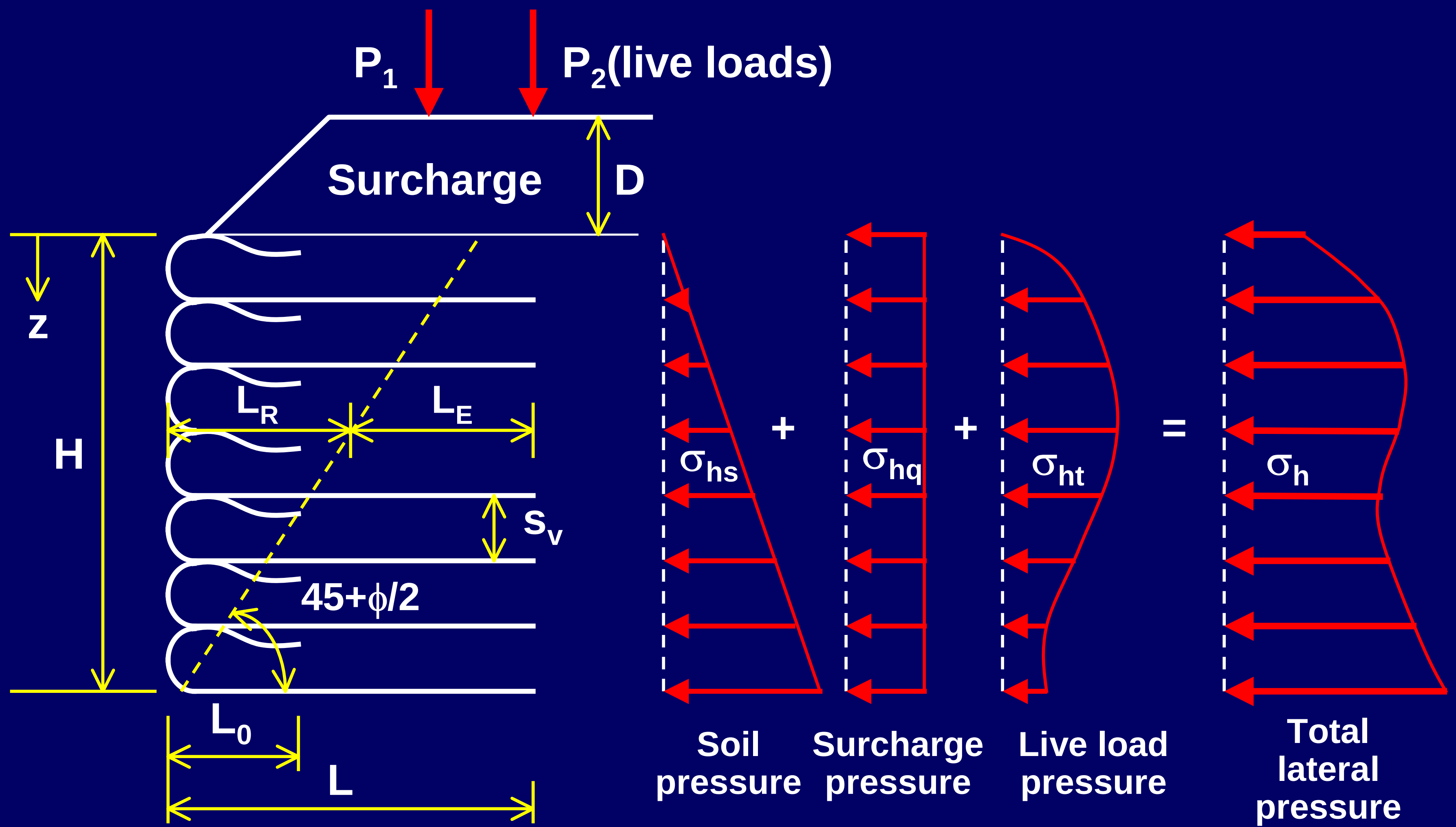
(after GRI Report No. 20, June 18, 1998)



Wall Reinforcement Design Concepts

- active earth pressure mobilized
- live loads via Boussinesq
- seismic loads require use of ground acceleration
- external design used to assess:
  - overturning stability
  - sliding stability
  - bearing capacity
- internal design results in:
  - spacing of GT or GG
  - length of GT or GG
  - facing connection stress
- reduction factors
  - on reinforcement strength for allowable strength
- factor-of-safety
  - on each design aspect to resist the “great unknown”

Elements of a GT or GG Wall Design



Example:

Design a 6 m high wrap-around wall to carry a surcharge of 10 kPa. Backfill is γ = 18 kN/m^3, ϕ = 36 deg., c = 0. The GT has T_{ult} = 50 kN/m and δ = 24 deg. Use FS = 1.4.

Solution: For <u>Internal Stability</u>

$$K_a = \tan^2\left(45 - \phi / 2\right)$$

$$= 0.26$$

$$\sigma_h = s_{hs} + s_{hq}$$

$$= K_a \gamma z + K_a q$$

$$\sigma_h = 4.68z + 2.60$$

now

$$T_{allow} = T_{ult}\left[\frac{1}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}}\right]$$

$$= 50\left[\frac{1}{1.2 \times 2.5 \times 1.15 \times 1.1}\right]$$

$$T_{allow} = 13.2 \text{ kN} / \text{m}$$

Solution: For Internal Stability *(cont'd)*

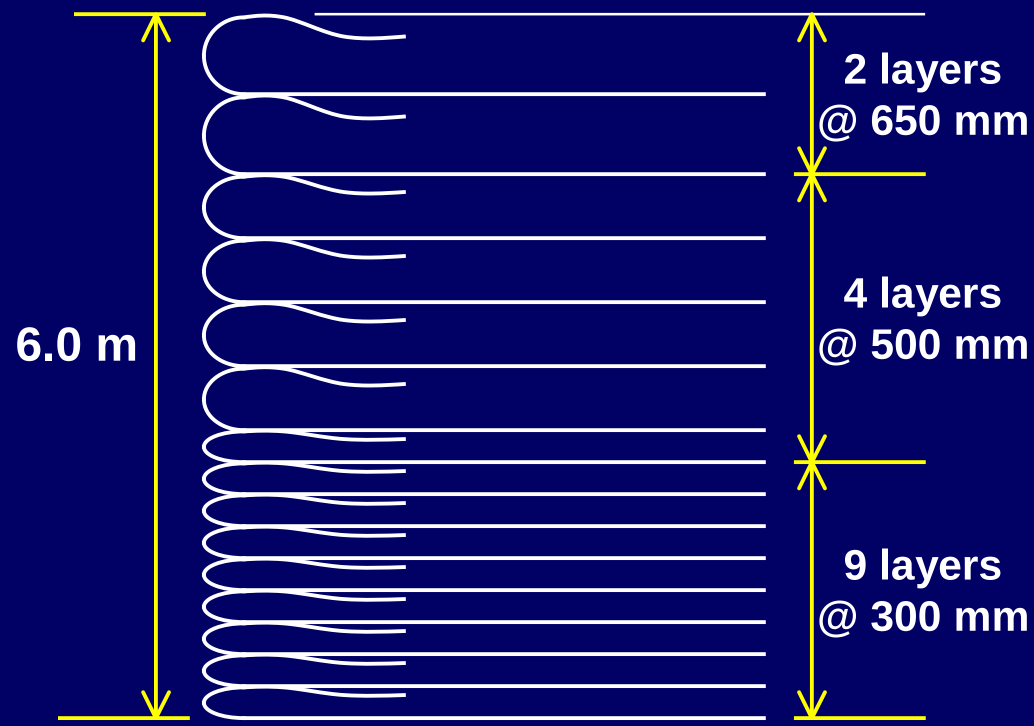
(a) the spacing of the reinforcement:

$$S_v = \frac{T_{allow}}{\sigma_h FS}$$

$$= \frac{13.2}{[4.68(6.0) + 2.60]1.4}$$

$$= 0.307 \text{ m}, \quad \text{use} \quad 0.3 \text{ m}$$

calculate at various depths "z", to get



Solution: For Internal Stability *(cont'd)*

(b) the length of the reinforcement:

$$L = L_e + L_R$$

$$L_e = \frac{S_v \sigma_h (FS)}{2(c + \gamma z \tan\delta)}$$

$$= \frac{S_v (4.68z + 2.60)1.4}{2(0 + 18z \tan 24)}$$

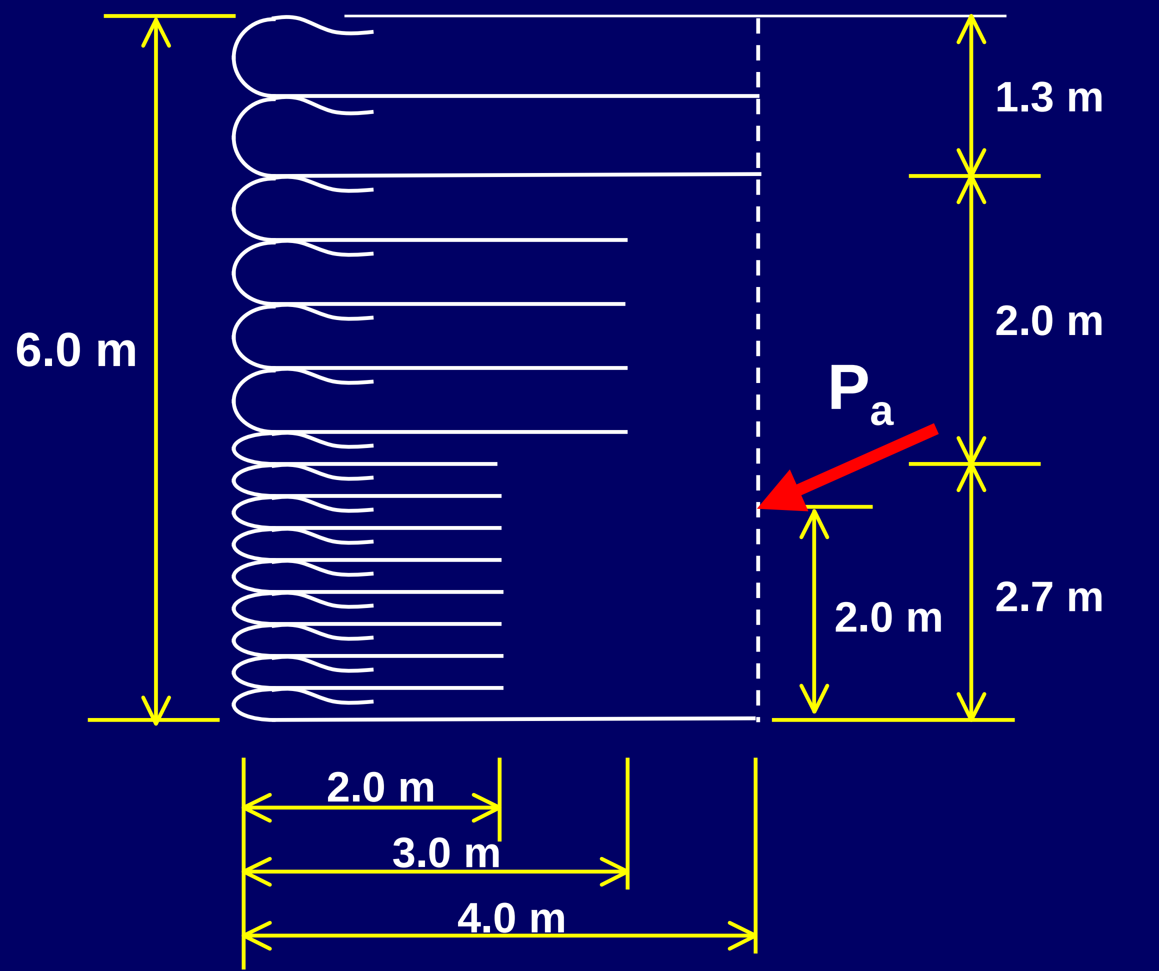
$$L_e = \frac{S_v (6.55z + 3.64)}{16.0z}$$

which must be added to the following (Rankine) length

$$L_R = (H - z)\tan\left(45 - \frac{36}{3}\right)$$

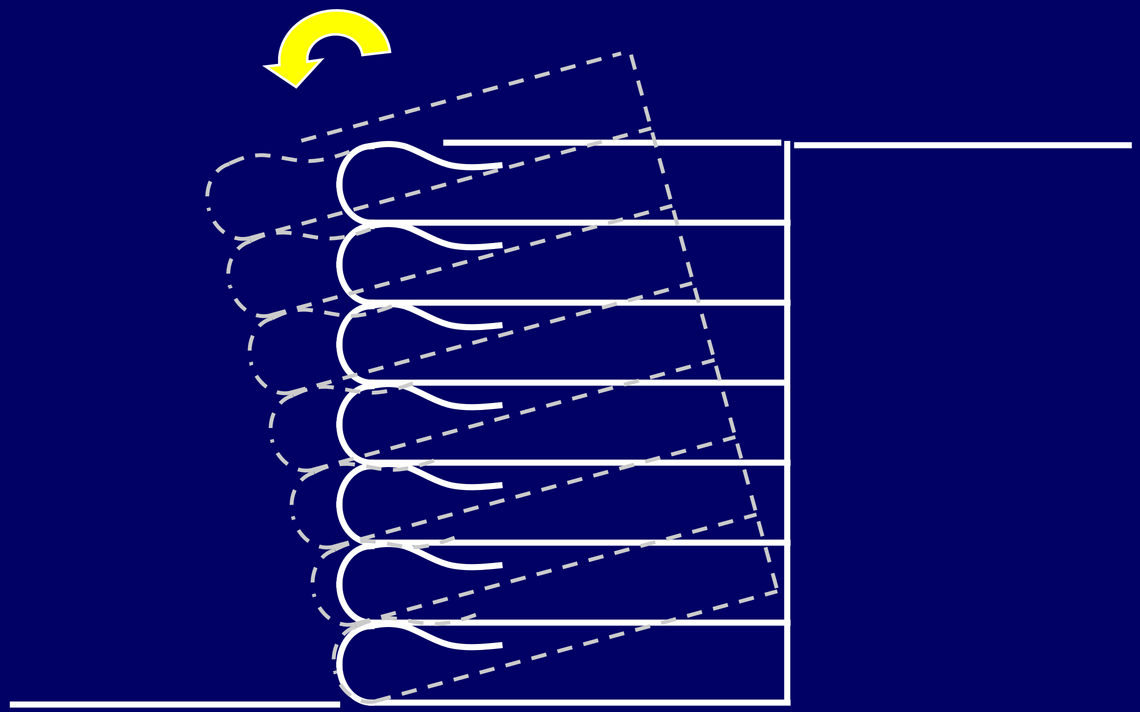
$$= (6.0 - z)(0.509)$$

Result of the Internal Stability Analysis



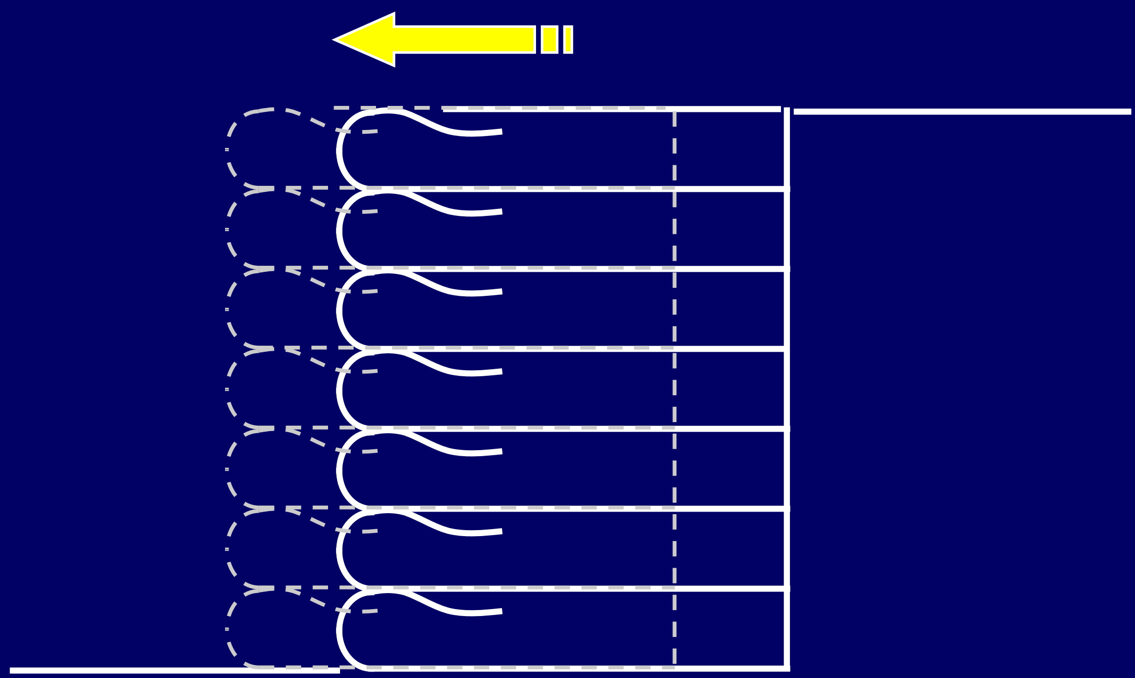
Solution *(cont'd)*: External Stability

(a) $\Sigma M_t = 0$; FS $\geq$ 1.5



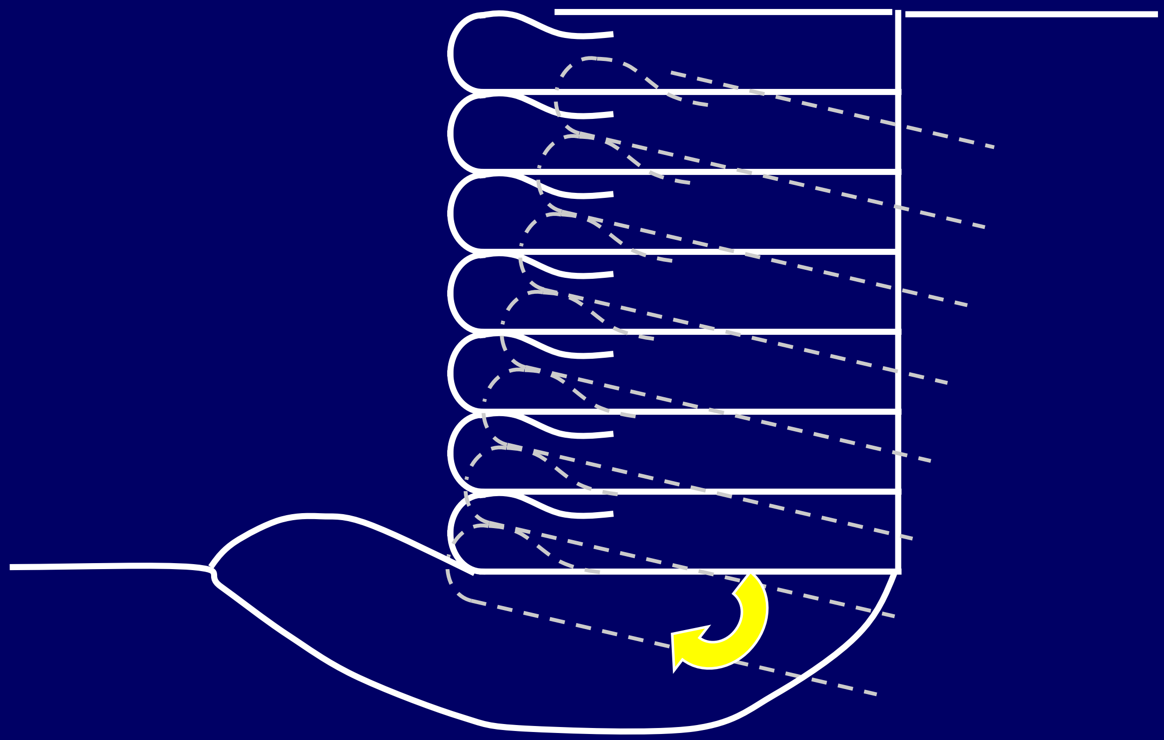
Solution *(cont'd)*: External Stability

(b) $\Sigma F_x = 0$; FS $\geq$ 1.5



Solution *(cont'd)*: External Stability

(c) $FS_{BC} = q_{allow}/q_{reqd} \geq 2.0$; where
$q_{allow} = cN_c + qN_q + 0.5\ gBN_g$
q_{reqd} = stresses from rein. soil mass

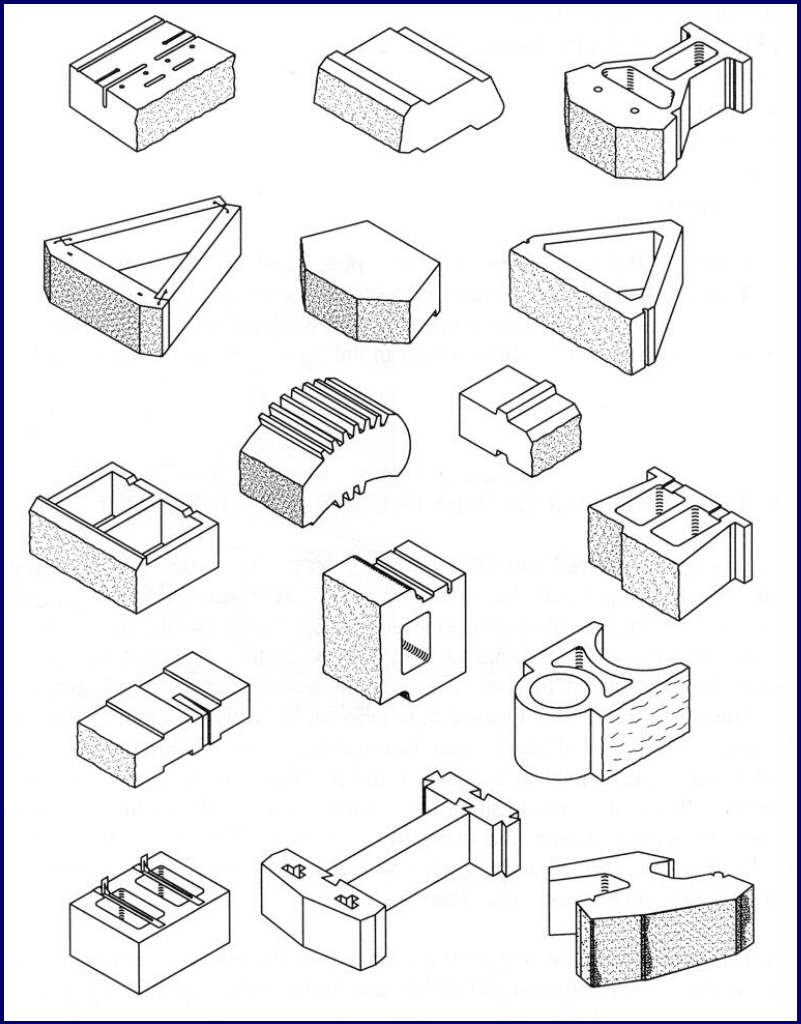


Wall Facing Types

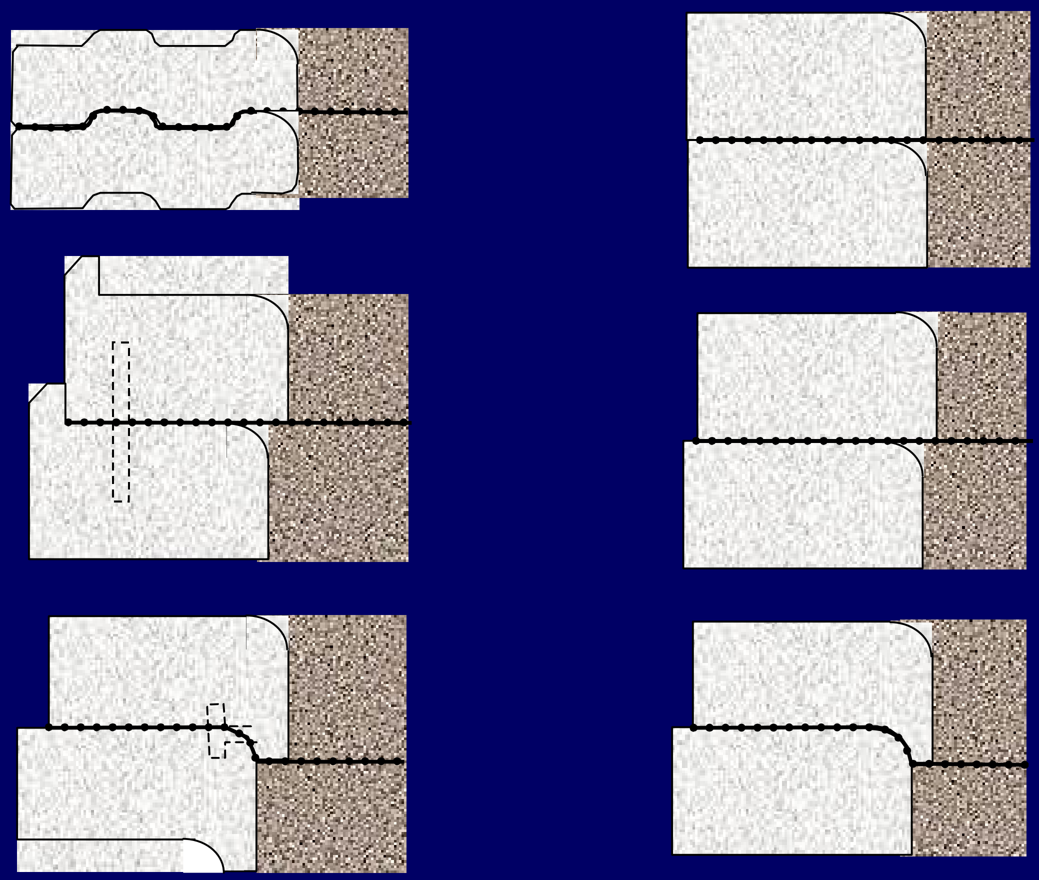
- wrap around facing
- full height precast panels
- articulated precast concrete facing elements
- cast-in-place concrete panels
- welded wire mesh facing
- gabion facing
- timber facing
- masonry block facing (called segmental retaining walls, or SRWs)

Examples of commercially available SRW units

(from Design Manual for Segmental Retaining Walls, NCMA, Herndon, VA)



Geosynthetic connection types for SRW units (note rounded edges on the lower blocks)



(above trailing lip is not recommended by authors)

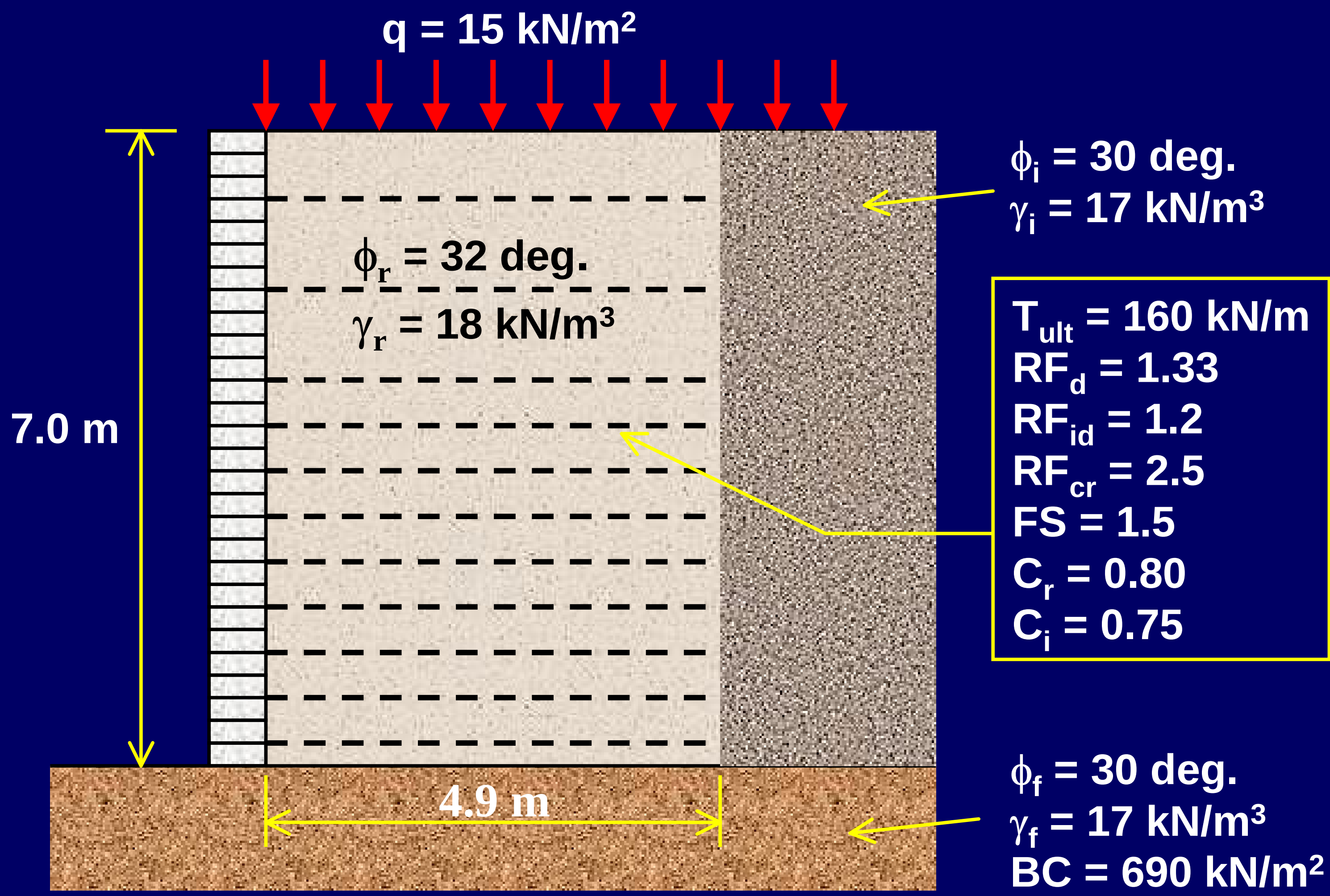
(above trailing lip is not recommended by authors)

Comparison of Design Methods

(Koerner and Soong, PennDOT/ASCE Conf., Hershey, PA, 1999)

- **modified Rankine - just presented**
- **FHWA via Demo '82 - for public walls**
- **NCMA - for private walls**

Numeric Example used to illustrate differences in design methodologies



Results of Numeric Example for Three Design Methods

(a) External Stability Considerations

Item	Modified Rankine	FHWA	NCMA
FS $_{Foundation\ sliding}$	2.07	2.30	2.87
Eccentricity (m)	0.64	0.65	0.42
FS $_{Bearing\ capacity}$	3.59	3.59	5.35
FS $_{Overturning}$	3.43	n/a	4.93

Results of Numeric Example for Three Design Methods *(cont'd)*

(b) Internal Stability Considerations

Reinforcement layer at El. 3.75 m is used for illustration

Item	Modified Rankine	FHWA	NCMA
tensile overstress[1]	2.88	2.84	2.91
soil pullout[1]	10.90	13.80	15.40
facing connectiont[2]	n/a	14.40	12.00

1 FS-values
2 reqd. conn. Strength (kN/m)
n/a not applicable

Comparison of Example Problem Results
"Assuming that FHWA has it right!"

Design Issue	Mod. Rankine	FHWA	NCMA
external stability			
• mass sliding	111%	100%	80%
• bearing capacity	100%	100%	67%
• overturning	100%	n/a	70%
internal stability			
• tensile overstress	99%	100%	98%
• soil pullout	123%	100%	85%
• facing connection	n/a	100%	83%

Thus:	mod. Rankine	= most conservative
	FHWA	= intermediate
	NCMA	= least conservative

For Additional Design Detail

- <u>Designing with Geosynthetics</u>, 4th Ed., 1998, R. M. Koerner
- AASHTO Specs for Bridge;s 1997 Interims (Sect. 5 - Ret. Walls)
- <u>MSE Walls and Slopes</u>
  FHWA Demo 82, Sept. 1998
  FHWA-SA-96-071 and
  MSE Walls Software,
  ADAMA Engineering Inc., Newark, DE
- <u>Segmental Retaining Walls</u>, 2nd Ed. 1997 NCMA, Herndon, VA,
  J. G. Collin, Ed. and SR Wall Software, Earth Improvement
  Technologies, R. J. Bathurst

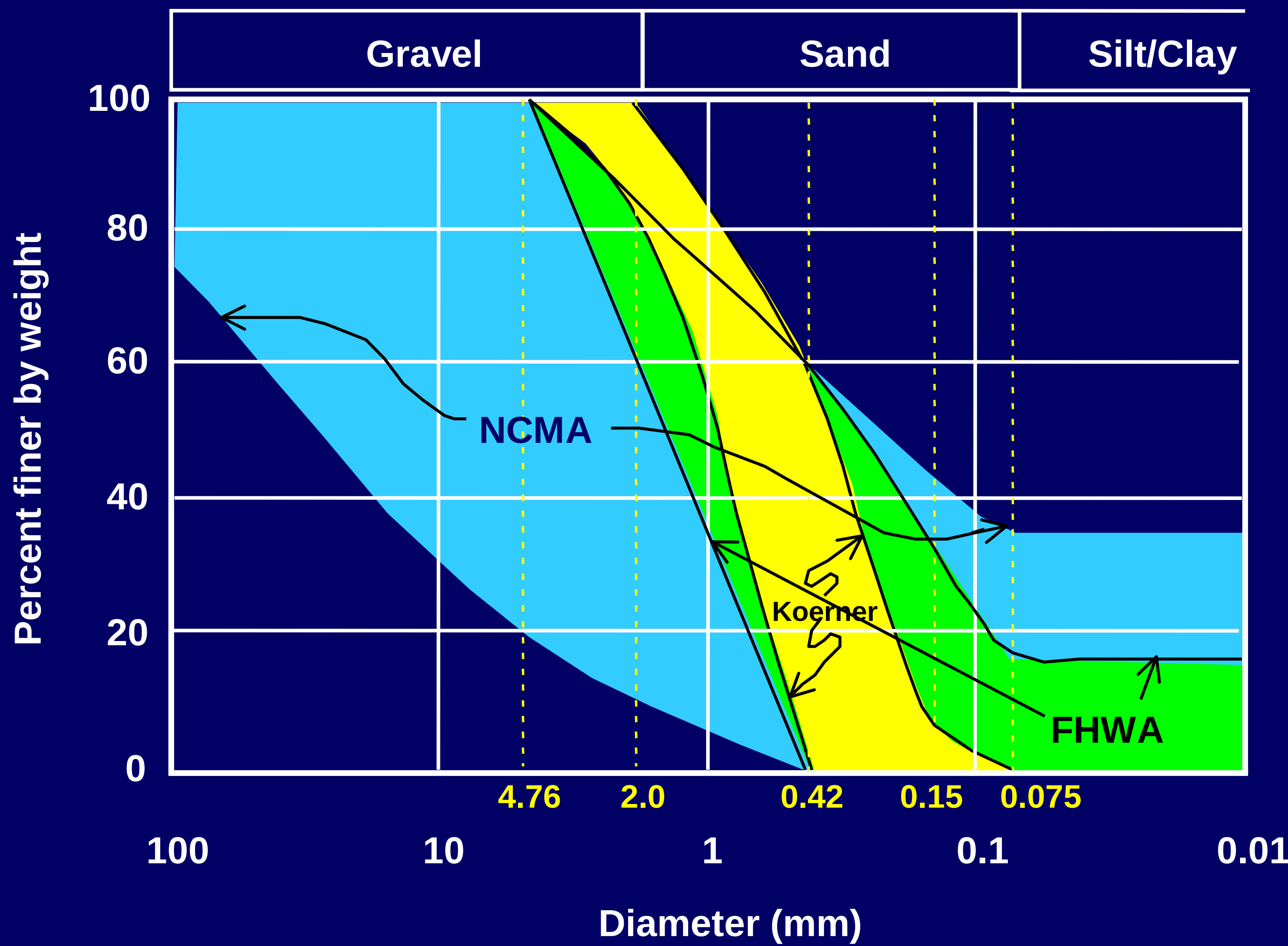
Issues Regarding MSE Walls

- durability of the reinforcement
- durability of the facing
- resistance of shear connections under seismic or dynamic loads
- impact damage to facing and subsequent repair
- utility (or other) excavation during service
- attention to design/installation details, particular internal and/or external drainage
- low permeability backfill soil

Reinforced Soil Zone Gradation Requirements

Sieve	Particle	Percent Passing Requirement		
Size	Size	Koerner	FHWA	NCMA
—	100 mm	—	—	75-100
No. 4	4.76	100	100	20-100
No. 10	2.0	90-100	—	—
No. 40	0.42	0-60	0-60	0-60
No. 100	0.15	0-5	—	—
No. 200	0.075	0	0-15	0-35

Reinforced Soil Zone Gradation Requirements



End of Section - 3